

Balloon borne soundings of water vapor, ozone and temperature in the upper troposphere and lower stratosphere as part of the second SAGE III ozone loss and Validation Experiment (SOLVE-2)

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1. Objectives

The main goal of our work was to provide in situ water vapor and ozone profiles in the upper troposphere and lower stratosphere as reference measurements for the validation of SAGE III water vapor and ozone retrievals. We used the NOAA/CMDL frost point hygrometer and ECC ozone sondes on small research balloons to provide continuous profiles between the surface and the mid stratosphere. The NOAA/CMDL frost point hygrometer is currently the only lightweight balloon borne instrument capable of measuring water vapor between the lower troposphere and middle stratosphere. The validation measurements were based in the arctic region of Scandinavia for northern hemisphere observations and in New Zealand for southern hemisphere observations and timed to coincide with overpasses of the SAGE III instrument. In addition to SAGE III validation we also tried to coordinate launches with other instruments and studied dehydration and transport processes in the Arctic stratospheric vortex.

2. Accomplishments

All soundings launched in this project carried the NOAA/CMDL frost point hygrometer as well as a Vaisala RS80 radiosonde for PTU measurement and data transmission. In addition most soundings carried an ECC ozone sonde and several also carried the Meteolabor Snow White hygrometer and a Vaisala RS90 radiosonde, which were used in sensor intercomparison studies. An overview of the soundings obtained up to present is given in table 1. The following discusses these soundings in detail.

Location	Instruments	# soundings
Sodankylä, Finland ^{*)}	FP/O3/SW/RS80/RS90	3
Sodankylä, Finland	FP/O3/RS80	2
Ny Ålesund, Norway	FP/PTU	4
Kiruna, Sweden	FP/PTU	3
Lauder, New Zealand	FP/O3/PTU	4

Table 1. Dedicated SAGE III validation soundings. The instruments used are: FP = NOAA/CMDL frost-point hygrometer, O3 = ECC ozone sonde, SW = Snow White sonde, RS80 and RS90 = Vaisala RS80-H and Vaisala RS90 radiosonde.

^{*)} The soundings at Sodankylä also match AIRS overpasses.

Arctic measurements

During the winter of 2002/2003 we launched a total of 11 frost point hygrometers in the Arctic at three different locations in cooperation with the Finnish Meteorological Institute and the Alfred Wegener Institute. Five soundings were launched at Sodankylä, Finland; three at Esrange near Kiruna, Sweden; and three at Ny Ålesund, Spitsbergen. The soundings at Sodankylä also carried ozone sondes, giving additional information about the air mass composition. Although the observations at Ny Ålesund were north of the SAGE III coverage, these measurements provide important information about the uniformity of the arctic stratospheric vortex and are used in some important transport study.

All arctic water vapor profiles are shown in figure 1. With the exception of the last sounding at Sodankylä on 4 April 2003 all soundings show a very similar structure indicative mostly of the interior of the vortex. Below 22 km some soundings show evidence of mid-latitude transport, which is discussed below.

SAGE III comparisons

The comparisons generally show a very good agreement between preliminary SAGE III retrievals and NOAA/CMDL water vapor profiles (figure 2). Features like the observations across the vortex edge on January 19 are reproduced well by the SAGE III retrieval (figure 2d). The Kiruna sounding on 12 January 2003 (figure 2c) shows higher water vapor values between 12 and 18 km compared to the SAGE III retrieval. This overpass event was close to Sodankylä, and about 250 km east of Kiruna, which make

inhomogeneities of the vortex an unlikely explanation for this discrepancy. The frost point sounding encountered a cloud layer beginning at 2 km and measured ice saturation up to the tropopause. Therefore, it is probable that the intake tubes were contaminated in this region, which provided an additional source of water vapor in the stratosphere. After the drying of the intake tubes, i.e. above 18 km this sounding shows a good agreement with the SAGE III retrieval. The descent data support this assessment, but are incomplete due to instrument failure at 15 km. The sounding scheduled to be launched the same day at Sodankylä was not released due to poor launch conditions.

LMD comparison

We obtained the first direct comparison between the LMD frost point hygrometer (Ovarlez, 1989) and the NOAA frost point hygrometer with the SAGE III overpass measurement on 16 January 2003 (figure 3). The LMD hygrometer is an instrument built at the Laboratoire de Meteorologie Dynamique and has been used at numerous European campaigns in the Arctic and several tropical sites. This instrument was launched at Kiruna, Sweden and NOAA hygrometers were launched at Kiruna and Sodankylä, Finland, about 400 km to the east of Kiruna and one day later on 17 January at Ny Ålesund. The NOAA hygrometer launched at Kiruna produced reliable data only up to 12 km and is only of limited use in this comparison. All soundings were launched well inside the vortex and show remarkably similar profiles at all altitudes above 10 km. These profiles show an excellent agreement. In addition they agree well with the preliminary SAGE III retrieval, which was obtained on the same day and slightly to the west of Kiruna. Therefore, these soundings clearly indicate that there is no systematic bias between the LMD and the NOAA hygrometer.

Arctic Dehydration

The fact that the Ny Ålesund sounding was launched one day later and roughly 1300 km further north, demonstrates that water vapor in the interior of vortex is remarkably homogenous in the absence of large scale dehydration as was the case in the winter of 2002/2003. However, there is some indication for small scale short lived dehydration at the beginning of December 2002. In this early period, the vortex was centered over northern Scandinavia and exhibited very cold temperatures. The sounding at Sodankylä on 6 December 2002 showed some layers of saturation in the stratosphere, without a significant reduction in water vapor (figure 4). The sounding at Sodankylä two days later shows a shallow layer of lower water vapor between 475 K and 500 K and another layer of lower water vapor between 510 K and 560 K (figure 5). These layers could either be remnants of dehydration or an indication of mid-latitude transport. The MIMOSA model was used to create a vertical cross section of modified PV at 27° longitude, which roughly corresponds to the balloon trajectory. This PV cross section (figure 6) shows the

transition from mid latitude to vortex air occurred between 475 K and 500 K. Here the lower of the two layers is clearly characterized as of mid-latitude origin. This region of lower water vapor can therefore be explained by transport of air with lower water vapor concentration from mid latitudes to this high latitude. A similar event was observed at Ny Ålesund on the 22 of January 2003 and was discussed in more detail by Müller et al. [2003]. The upper layer between 510K and 560 K on the other hand, is clearly characterized as vortex air. A trajectory analysis at 550 K shows that the temperatures in this layer were cold enough for ice particle formation and removal of water. Thus, the slightly lower water vapor concentration observed in this layer is likely the result of dehydration and similar to other events observed in the Arctic in January of 1996 and January of 2000 [Vömel et al., 1997, Schiller et al., 2002]. However, it is remarkable to observe this kind of event that early in the winter.

Southern Hemisphere Observations

Lauder, New Zealand was chosen as the Southern Hemisphere validation site. This site is near the northern most latitude of the southern hemisphere, which is still covered by SAGE III overpasses. Furthermore, frost point observations have been launched at Lauder in the past and this site is planned to become a routine sounding site for stratospheric water vapor soundings.

Four soundings total were launched at Lauder, two in March and two in November of 2003. The results are shown in figure 7 and the comparisons of preliminary SAGE III and frost point water vapor profiles for the March soundings is shown in figure 8.

The sounding on 14 November 2003 shows unusually high amounts of water vapor in the lowermost stratosphere. The data shown here are ascent data only and the high values may be indicative of contamination that was carried upward on the balloon train. Descent data are not available and thus there is no verification of these values during the descent phase of the sounding. However, the ozone profile also shows a very unusual minimum in the same altitude region and may indicate a transport process, which moved tropospheric air with low concentrations of ozone and relatively large concentrations of water vapor into the lowermost stratosphere, bypassing the cold trap of the tropical tropopause.

3. Instrument performance

We launched a total of 16 frost point hygrometers as part of this project. Of these 14 produced water vapor data up to at least 25 km. The sounding at Kiruna on 16 January 2003 reached 10 hPa, but the balloon failed to burst and continued to float. This sounding only provided ascent data, which were contaminated above 12 km by the outgassing of balloon and load line. Descent data, which are normally used, were not available in this sounding. The sounding at Ny Alesund on 18 December 2002 suffered from a failure of the onboard interface board during launch. No hygrometer data were transmitted. The soundings at Sodankylä and Lauder used a different interface board, which has shown to be less sensitive to interference and which has become the interface of choice since.

We also encountered the failure of one piece of the ground equipment during the sounding at Ny Alesund on 12 December 2002. This sounding was subsequently recorded on tape using a backup receiver and analyzed after sounding termination. This failure led to a loss of data between 3 km and 8 km. The stratospheric ascent and descent of this sounding was recorded in its entirety. All soundings at Sodankylä, Finland and Lauder, New Zealand were recorded by two independent ground systems even though no complications were encountered.

4. Figures:

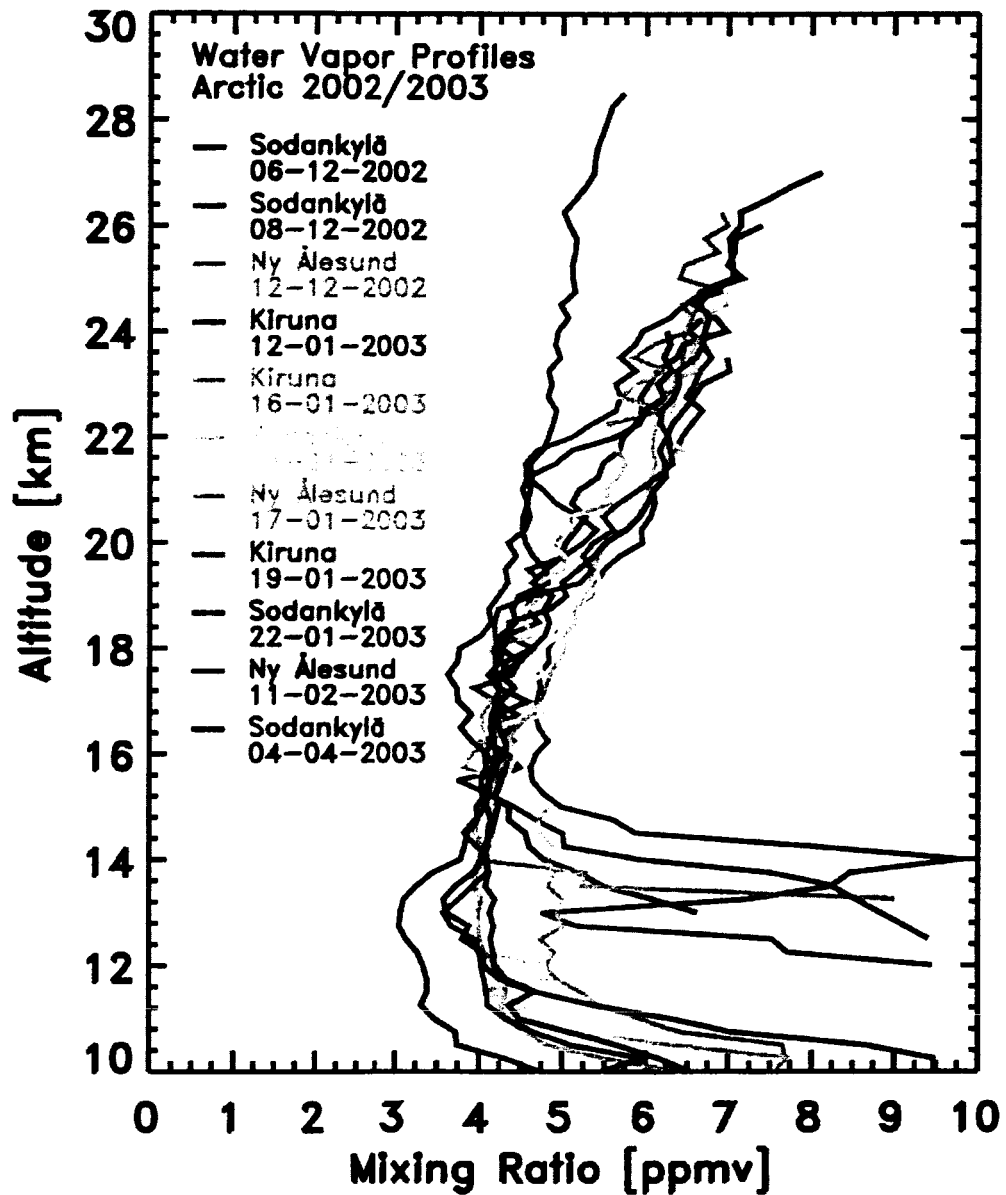


Figure 1: Summary of all Arctic soundings in the winter 2002/2003. Sounding sites are Ny Ålesund, Spitzbergen; Kiruna, Sweden; and Sodankylä, Finland. Above 22 km all soundings before April show high values characteristic of vortex air.

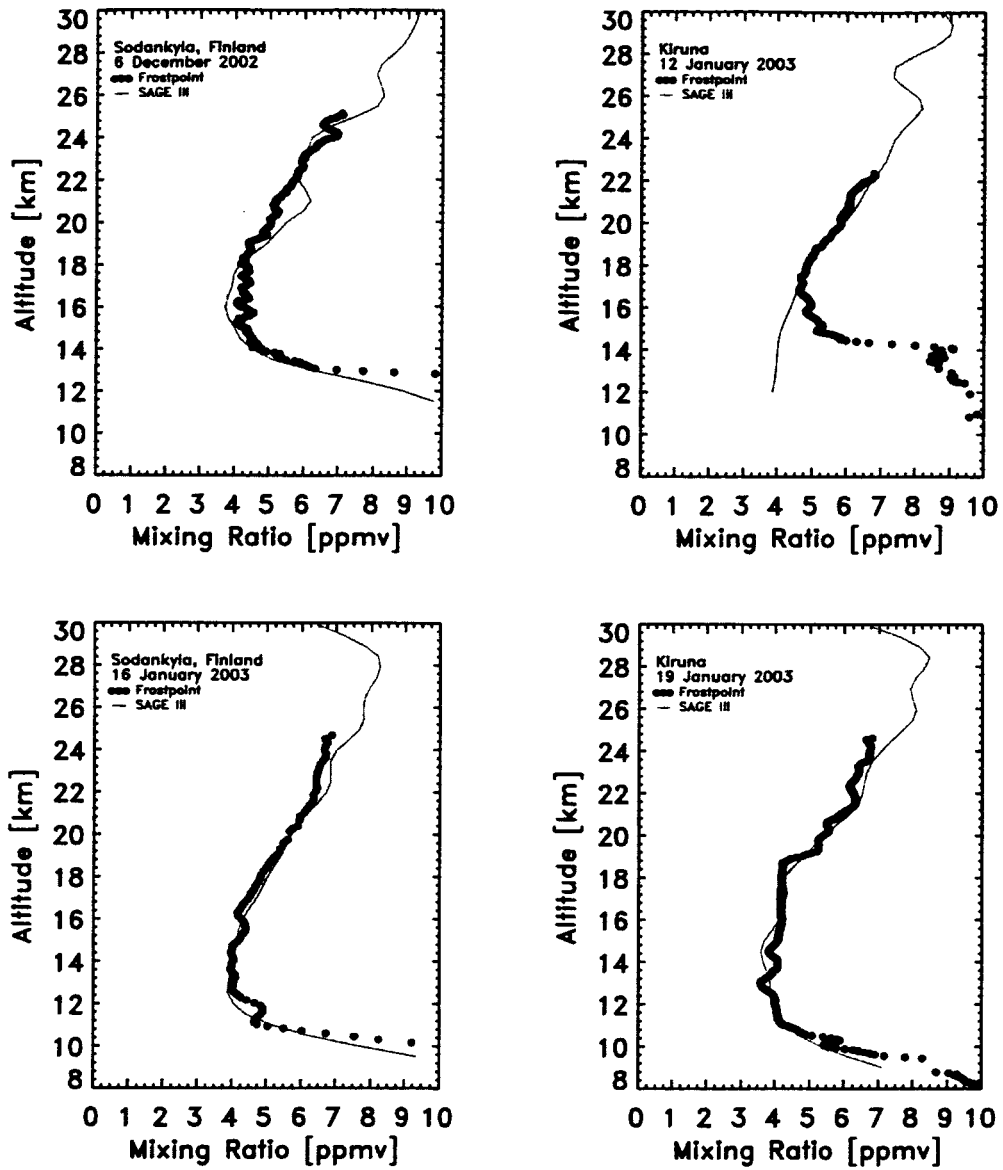


Figure 2: Comparison between preliminary SAGE III retrieval and NOAA frost point water vapor profiles for 4 selected arctic soundings.

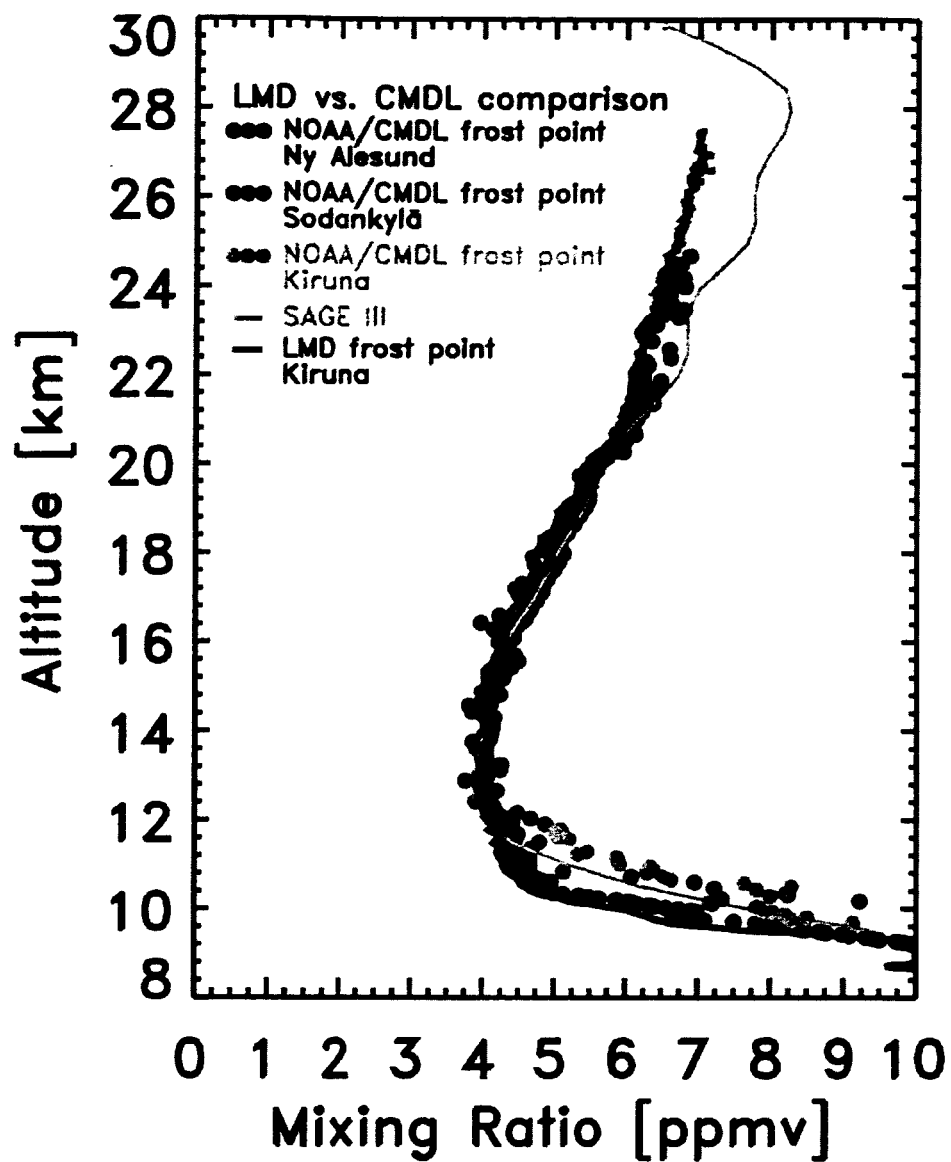


Figure 3: Comparison between the LMD frost point hygrometer and the NOAA/CMDL hygrometer show excellent agreement between the instruments flown on 16 January 2003 at Kiruna and Sodankylä and on 17 January 2003 at Ny Ålesund as well as a preliminary SAGE III retrieval.

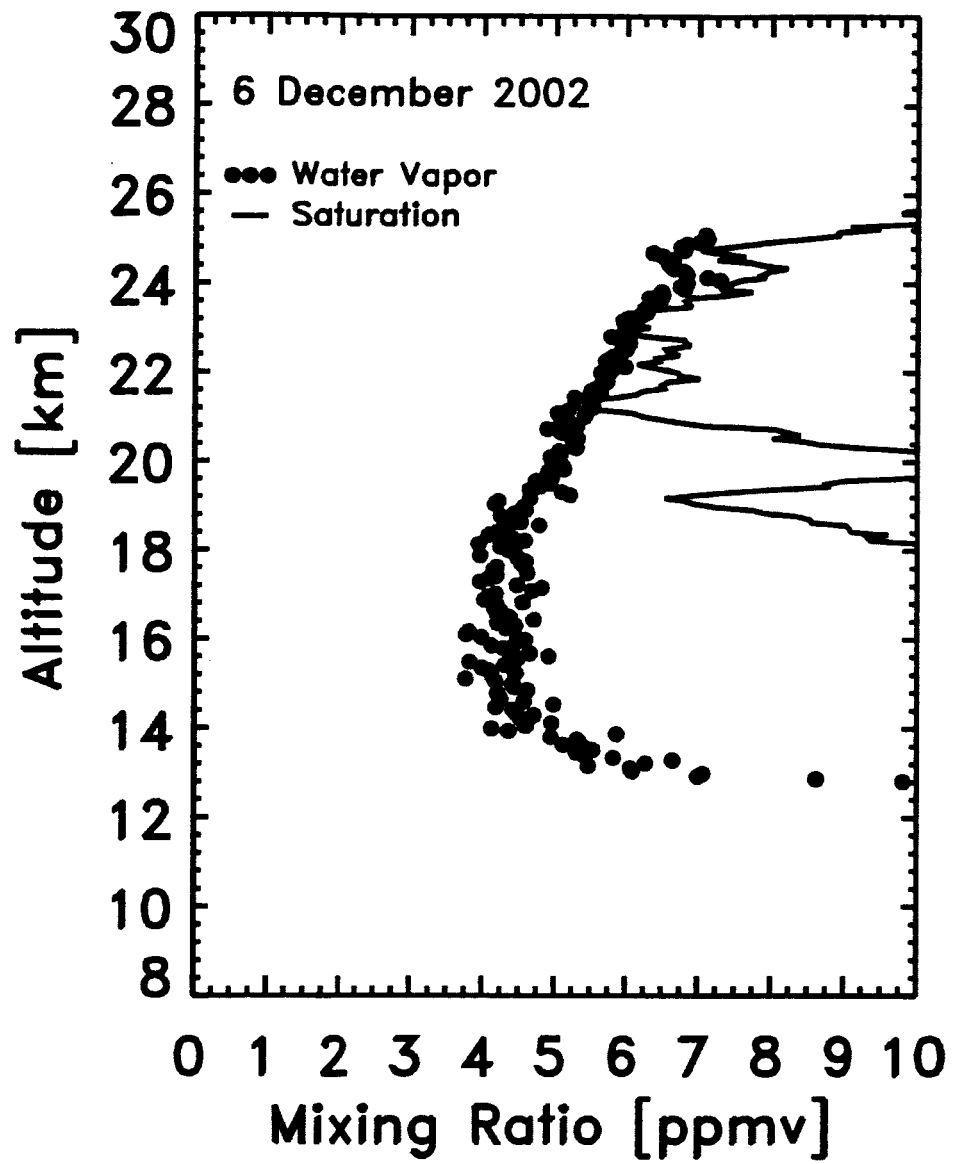


Figure 4: Water vapor and saturation mixing ratio profiles at Sodankylä, 6 December 2002. Note some shallow layers of saturation between 21 and 25 km.

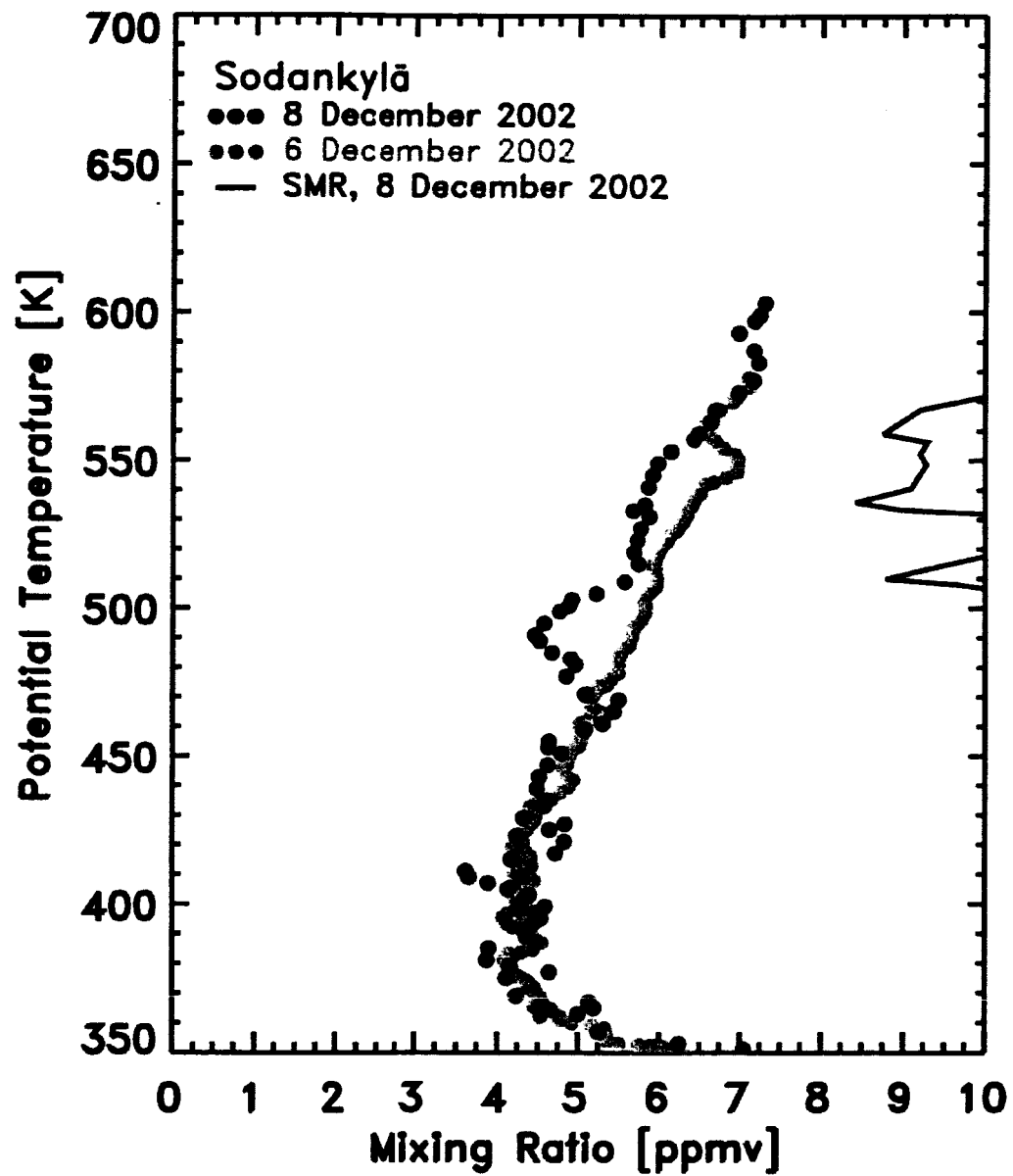


Figure 5: Water vapor profiles on 8 December 2002 at Sodankylä compared to the sounding 2 days prior. Also shown is the saturation mixing ratio for the sounding on 8 December 2002.

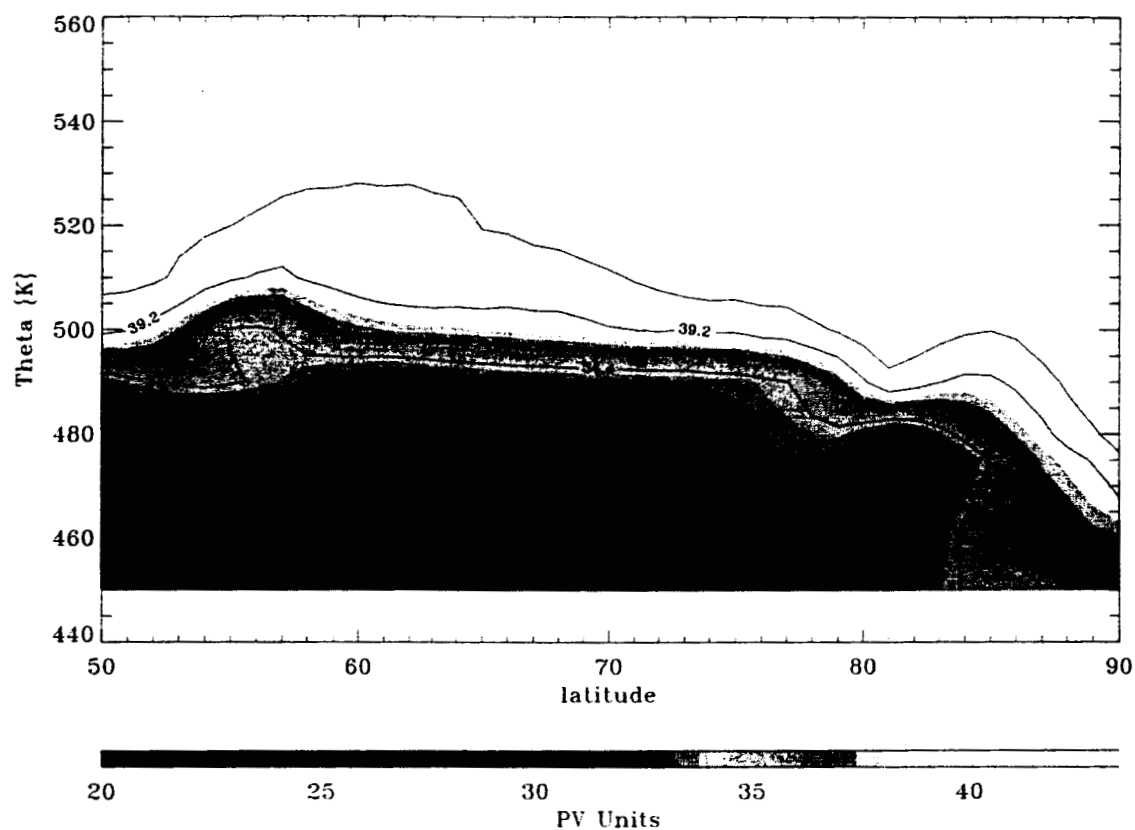


Figure 6: Vertical cross section of modified PV at 27° longitude corresponding to the balloon trajectory shows the transition from mid latitude to vortex air between 475 K and 500 K. Red and blue colors indicate mid latitude air, light colors indicate vortex air. This transition corresponds to the lower of the two layers showing reduced water vapor. Sodankylä is located at 67°N.

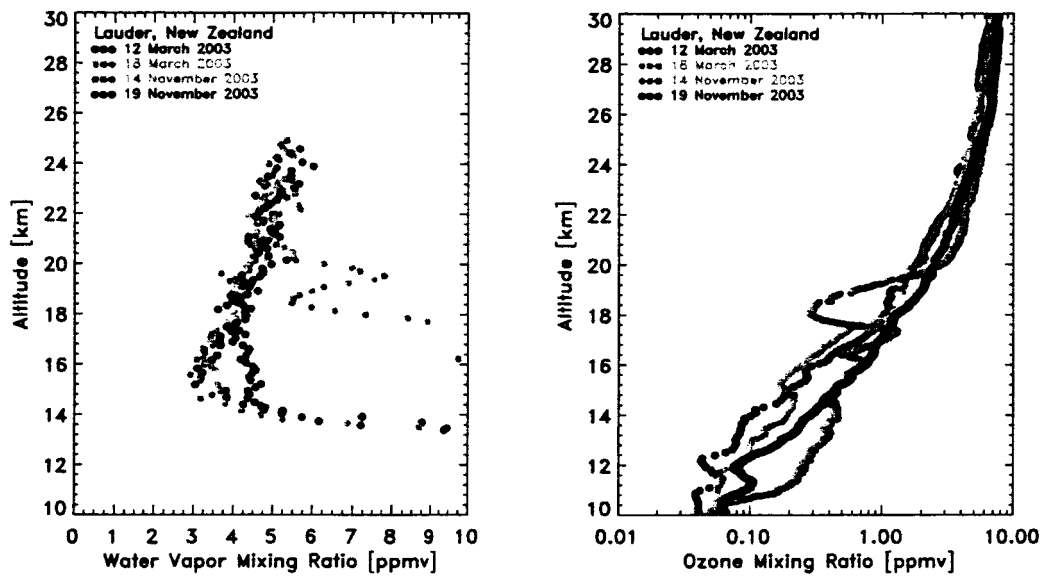


Figure 7: Summary of all soundings at Lauder, New Zealand in March and November of 2003. Left: water vapor, right: ozone.

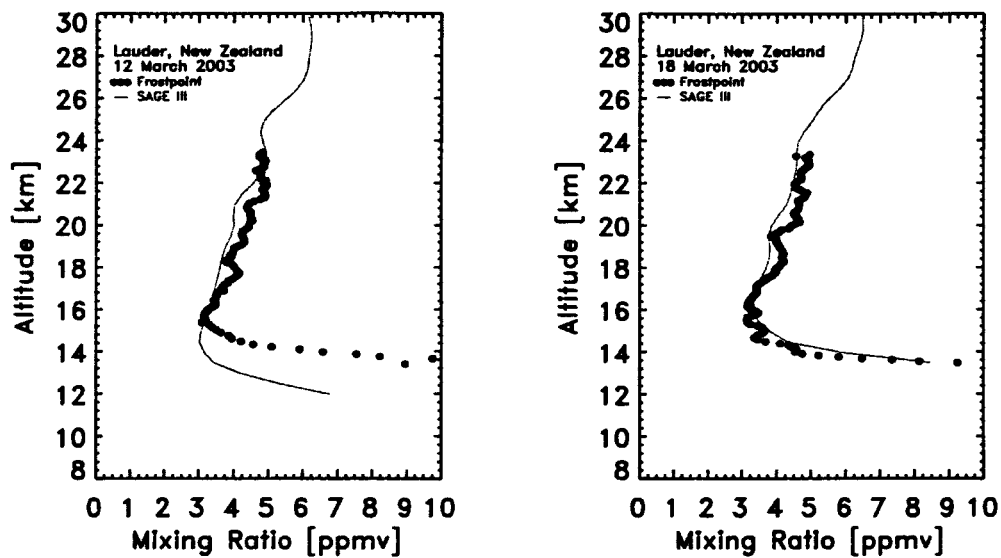


Figure 8: Comparison between preliminary SAGE III retrieval and NOAA frost point water vapor profiles for the March 2003 soundings at Lauder, New Zealand.

5. References

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